The MTI Dense-Cloud Mask Algorithm Compared to a Cloud Mask Evolved by a Genetic Algorithm and to the MODIS Cloud Mask

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ABSTRACT

In support of its dual mission in environmental studies and nuclear nonproliferation, the Multispectral Thermal Imager (MTI) has enhanced spatial and radiometric resolutions and state–of–the–art calibration capabilities. These instrumental developments put a new burden on retrieval algorithm developers to pass this accuracy on to the inferred geophysical parameters. In particular, current atmospheric correction schemes assume the intervening atmosphere is adequately modeled as a plane–parallel horizontally–homogeneous medium. A single dense-enough cloud in view of the ground target can easily offset reality from the calculations, hence the need for a reliable cloud–masking algorithm. Pixel–scale cloud detection relies on the simple facts that clouds are generally whiter, brighter, and colder than the ground below; spatially, dense clouds are generally large, by some standard. This is a good basis for searching multispectral datacubes for cloud signatures. However, the resulting cloud mask can be very sensitive to the choice of thresholds in whiteness, brightness, and temperature as well as spatial resolution. In view of the nature of MTI's mission, a false positive is preferable to a miss and this helps the threshold setting. We have used the outcome of a genetic algorithm trained on several (MODIS Airborne Simulator–based) simulated MTI images to refine an operational cloud–mask. Its performance will be compared to EOS/Terra cloud mask algorithms.

Keywords: MTI, Multispectral Imaging, Cloud Masks, Genetic Algorithms

1. INTRODUCTION

The dual primary missions of the Multispectral Thermal Imager (MTI) spacecraft are environmental studies and nuclear non-proliferation. In order to study the images from the spacecraft, atmospheric effects such as water vapor absorption or aerosol scattering must be removed. Also, clouds, which limit seeing of the ground, routinely must be removed from the images. For the MTI spacecraft, efforts have been made to limit analyst requirements. Most software is automated to some degree.

Thus, using the simple definition that clouds are white, bright, and cold, analysts are required to determine three thresholds explicitly for each image: an upper limit on temperature, a lower limit on whiteness, and a lower limit on brightness (as determined by a classic NDVI scheme). While fundamentally there is a lot more science to clouds' radiative properties, for the primary purpose of the MTI mission, clouds are a perturbation that must be flagged. Therefore it is important to quickly sort data into "cloud" and "non–cloud" categories, rather than to classify the types of clouds. The classification of clouds will be a focus for future work with the MTI data.

The MTI spacecraft[1] was launched on March 12, 2000. A collaborative project between Los Alamos National Laboratory, Sandia National Laboratory and Savannah River Technology Center, MTI's mission objectives are to advance the state of the art in multispectral and thermal imaging, image processing, and to better understand the usefulness of these data. MTI has 15 multispectral bands (see Figure 1), including three visible bands, five very near infrared, two short–wave infrared, two mid-wave infrared and three longwave infrared.[2]

The MODIS Airborne Simulator (MAS)[3] is a high resolution scanning spectrometer that is carried on-board a NASA ER–2 high–altitude aircraft. Its primary objective was to help create and assess algorithms for the MODerate

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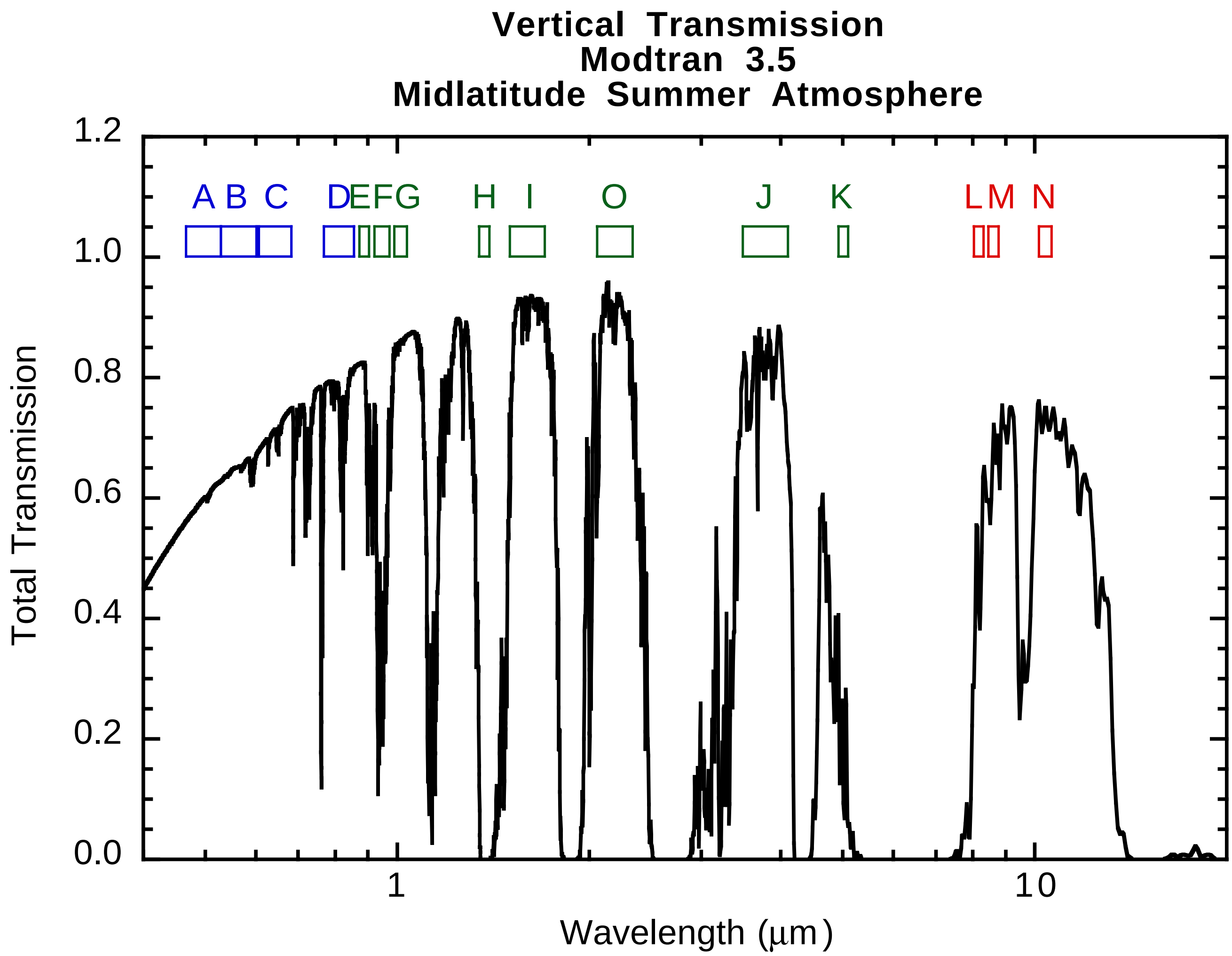

Figure 1. MTI bands shown above a model atmospheric transmission profile from Clodius, *et al.*[2]. Bands C, E, and N are used for the MTI simple–threshold cloud mask (see Section 2.1).

resolution Imaging Spectroradiometer (MODIS) on board the TERRA spacecraft. In this work, spectrally resampled MAS data is used as a proxy for the MTI spacecraft data. The data is from the Smoke, Clouds, And Radiation - Brazil (SCAR-B) campaign to study tropospheric aerosol radiative forcing.

The MODIS cloud mask was developed for use on MAS data. *Ackerman et al.*[4] describe this physics-based algorithm. Their method involves categorizing the scene into night, day and type of land-cover (e.g. desert), then they classify the types of clouds based on thresholds and adjacency requirements for the specific type of cloud being assessed.

GENIE (see *Brumby et al.,*[5] and references therein) is an evolutionary computation software system, using a genetic algorithm to assemble image-processing tools (retrieval algorithms) from a collection of low-level image operators (e.g., texture measures, spectral band math, edge detectors, various morphological filters). A population of candidate tools is generated, ranked according to a fitness metric measuring their performance on some user-provided training data, and fit members of the population permitted to reproduce. Each tool generates a number of intermediate feature planes, which are then combined using a supervised classifier (currently a Fisher discriminant and intelligent threshold function) to generate a final result mask. This process cycles until the population converges to a solution; or the user decides to accept the current best solution, or to change the training data. GENIE is free to ignore the spatial information in the image and rely wholly on spectral band math and the supervised classifier, but in practice GENIE will construct integrated spatio-spectral algorithms. These have been shown to be effective in looking for complex terrain features, such as golf courses.[6]

As with all machine learning systems, performance depends crucially on the provision of a sufficient quantity of well-chosen training data and supplying this data is typically a major challenge. For GENIE, training data is provided via a graphical user interface. The user is able to influence the evolution of algorithms by providing additional information, and by interactively providing additional training data. While this method has been applied to many different remote-sensing problems, we started this investigation to explore its usefulness for the important task of cloud–finding.

2. ALGORITHMS

2.1. Image Dependent Simple–Threshold Method

For the MTI cloud masking algorithm, we use three basic descriptive criteria about clouds to determine the cloud mask: brightness, whiteness, and temperature.[7] In order for the mask to work well, we need data from at least a visible, a near infrared band, and a thermal band. We use bands "C", "E", and "N".

Observationally, clouds are usually much brighter than their background. They can be considered to be lambertian. Their brightness is caused by refraction by the ice crystals and water droplets that make up the cloud. Clouds usually appear white when viewed from above. Due to the altitude of the clouds, they are cold. Often, they appear much colder than their background, when viewed from above - ranging from perhaps greater than 20°C to -60°C depending on their opacity and altitude.

For MTI we developed a simple procedure. We use a normalized dense vegetation index (NDVI) to determine whiteness, the red band to determine brightness, and the thermal band to determine a relative temperature, using simple–thresholds on each of these. While these codes are mostly automated, this routine requires that the thresholds be determined by hand – selecting representative cloudy pixels in an RGB display. In this RGB rendering, we assign B to band "C" (red), G to band "E" (near IR), and R to "N" (thermal IR); dense-enough clouds appear in a distinctive cyan blue. Figure 2 illustrates this simple algorithm. This routine is part of the Level 2 data processing for regular data retrievals for MTI.

2.2. MODIS Method

Ackerman et al.,[4] describe the cloud mask developed for the MODIS instrument on board the Terra Spacecraft. Here we summarize their methods. Their automated masking routines specify pixels that are optically thick aerosol, clouds or shadow. It returns a 48 bit cloud mask that includes much information, that includes a two bit classification for the likelihood that a given pixel is cloudy. This cloud mask is based on radiance values in seventeen bands plus ancillary data: spacecraft viewing geometry, land/water/ice map, topography, etc.

Here is a brief description of the mask implementation.[4] The pixel is set to land, water, or coast from an ancillary data set. Next its ecosystem is determined. Adjustments are made for whether it is in a sun glint region.

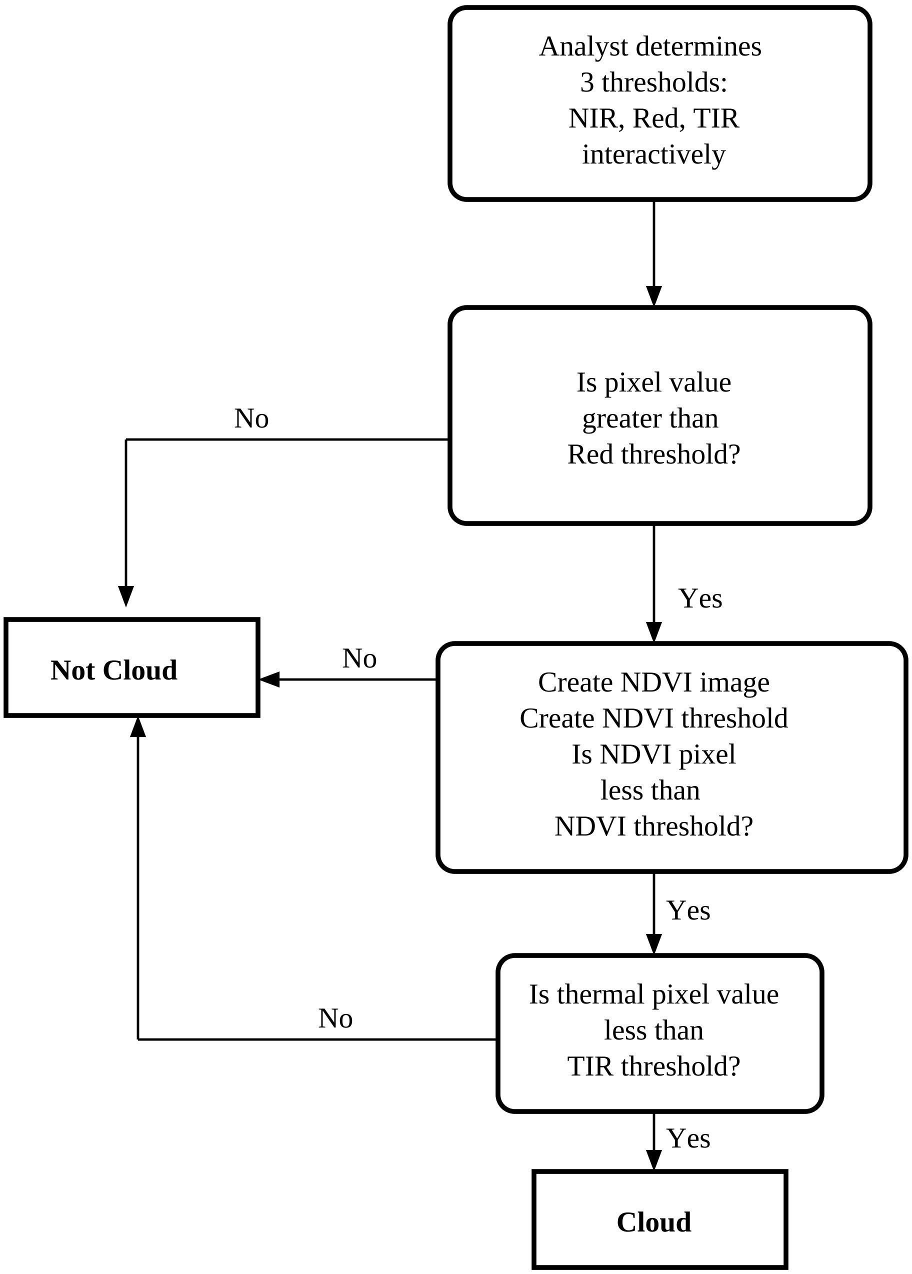

Figure 2. Flow chart of the MTI simple thresholding algorithm. See Section 2.1 for details.

It is assigned day or night status. A special adjustment is necessary if snow or ice is in the image. The appropriate masking test based on all of the attributes that have now been assigned to the pixel is applied. This last step assigns a value to the pixel, each pixel will then be either clear (with high confidence), probably clear, maybe clear and likely cloudy with those designations defined via use of a threshold. Any pixel not labeled clear with high confidence will be considered cloudy for our cloud mask comparison.

2.3. GENIE

The MODIS cloud mask was run on several scenes from the MAS SCAR-B flight series (95-162, 95-163). The 2-bit cloud cover classification provided the training data for GENIE. We chose to use the most conservative cloud finding setting, so any pixels classified as even possibly cloudy were marked as true for GENIE's training data.

A population of 100 candidate tools, each consisting of 20 primitive image processing steps, was evolved for 100 generations. This evolution required a few hours compute time on a LINUX workstation. The evolved solution produced a good match to the training data, and compared to the MODIS cloud mask we achieved a detection rate of 95% and a false alarm rate of 6.1%, as shown in Table **??**.

Each candidate tool generates five feature planes. We use the contents of these planes to derive the Fisher discriminant, which is the linear combination of the feature planes that maximizes the mean separation in spectral terms between those pixels marked up as "true" and those pixels marked up as "false", normalized by the "total variance" in the projection defined by the linear combination. See Bishop[8] for details of this discriminant. The output of the discriminant-finding phase is a gray-scale image. This is reduced to a binary image by using Brent's method[9] to find the threshold value that minimizes the total number of misclassifications (false positives plus false negatives) on the training data.

It is possible to analyze the evolved algorithm to determine if all the features contribute to the final answer. In the present case, we found that only two features planes were significant, and we present a flow chart of the reduced algorithm that generate just those feature planes in Figure 3.

The algorithm consists of two independent blocks:

(A) MAS band 2, 0.653 μm visible red, spectrally equivalent to MODIS band 13 and MTI band "C", undergoes a linear contrast stretch, but is otherwise passed without alteration to the Fisher discriminant.

(B) MAS band 35, 4.465 μm MWIR, equivalent to MODIS band 24 and similar to MTI band "J", undergoes local gradient spatial processing, equivalent to the difference of the standard morphological filtering operations of greyscale dilate and erode. A scalar constant is subtracted from the output, and the result is clipped at the 95% level. An NDVI-like ratio is formed of this processed result and the MAS band 1, 0.659 μm visible red.

To test generalization of the evolved algorithm, we ran our algorithm without modification on two other scenes from the SCAR-B flight series, the results of which are also shown in Table **??**. Generalization is quantitatively good, and is in fact equal to performance on the training image because of the generally reduced complexity of types of clouds present in other flight tracks in the SCAR-B sequence.

3. METHOD COMPARISON

Figure 4 shows a portion of the cloud image from the SCAR-B data set. It is from flight 95–163. Panel a shows the clouds in the image using a near infrared band (similar to MTI band "E") from the MAS data. Panel b shows the clouds determined using a simple–threshold scheme. Panel c shows the MODIS cloud mask for this image. Panel d shows the GENIE results for this data. Here it is important to note that GENIE discovered some false positive pixels in the MODIS cloud mask. The GENIE cloud mask and the cloud mask determined from simple thresholds are quite similar. This leads to greater confidence in the simple–threshold applicability to this particular data set. Note also that the false positives in the lower left edge of the image in the cloud mask from MODIS are not replicated with the simple–threshold routine. Caution is necessary, however, as the similarities and differences between the cloud masks should not be generalized to snowy or night scenes.

Each cloud detection method mentioned above has positives and negatives associated with it. Here several of these aspects are described.

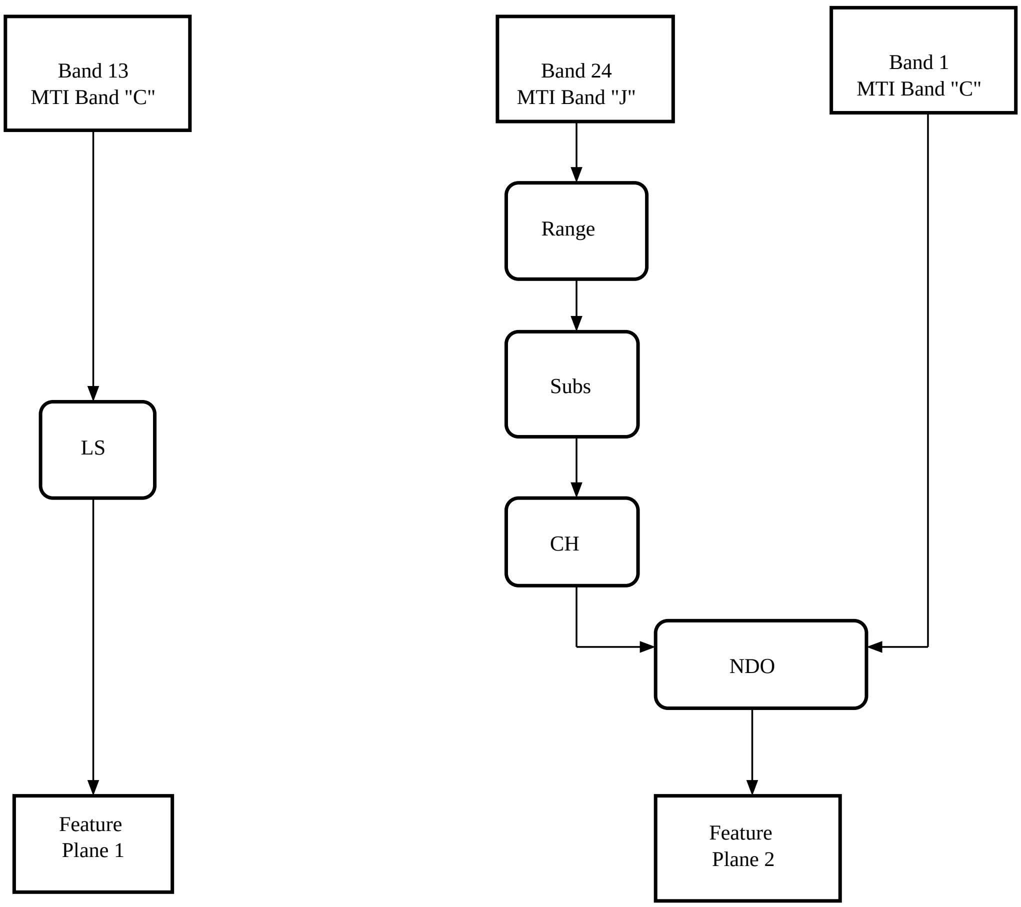

Figure 3. Two contributing feature planes evolved for a cloud mask on SCAR-B data. See Section 2.3 for details.

The simple–threshold method requires a user to interface and determine the thresholds for each image, this process takes on the order of minutes. The computation time for this method is then minimal, on the order of a second or two. The mask is sufficiently accurate, with the possible exception of images that contain both snow and clouds.

The MODIS cloud mask uses a variety of physics–based tests for various types of clouds. This requires a great deal of ancillary data instead of user determined thresholds. It does better over snow and ice than the simple–threshold method because the ancillary data estimates the likelihood of snow and ice. It is computationally intensive, taking minutes to run, and a great deal of memory.

GENIE requires a user to provide training data. The evolution process takes a few hours, but after it has evolved a solution, it takes seconds to run on any particular image. It is not as memory intensive as the MODIS cloud mask. Finally, unlike either of the other methods, it has a quantifiable error rate (on the training data). This instills more confidence (assuming the error rate is low) on the user end, though in principle generalization of the algorithm needs to be shown on a case–by–case basis. In practice, we find that the evolved algorithm does tend to generalize well.

The algorithm evolved by GENIE for this particular cloud mask application uses a thermal infrared band and a red band. This is similar to the method used with the simple–thresholds, though the band choices are not identical.

4. SUMMARY

We have created a cloud mask using simple, user–defined thresholds. This mask compares quite favorably to the MODIS cloud mask. While it does require user intervention, it does not require large amounts of processing time or disk space. We have also compared our results to an evolved solution for masking clouds created with a genetic algorithm. Again, the simple method compares favorably to the genetic algorithm derived mask.

All three methods have strong points and drawbacks. We plan to continue the comparison between the GENIE cloud masks and the MODIS cloud mask more quantitatively in future work. Also, we plan to use both GENIE and the MTI cloud mask on a regular basis in detection products for the MTI spacecraft. For the time being, though, our level 2 masking algorithm will remain the simple–thresholding procedure.

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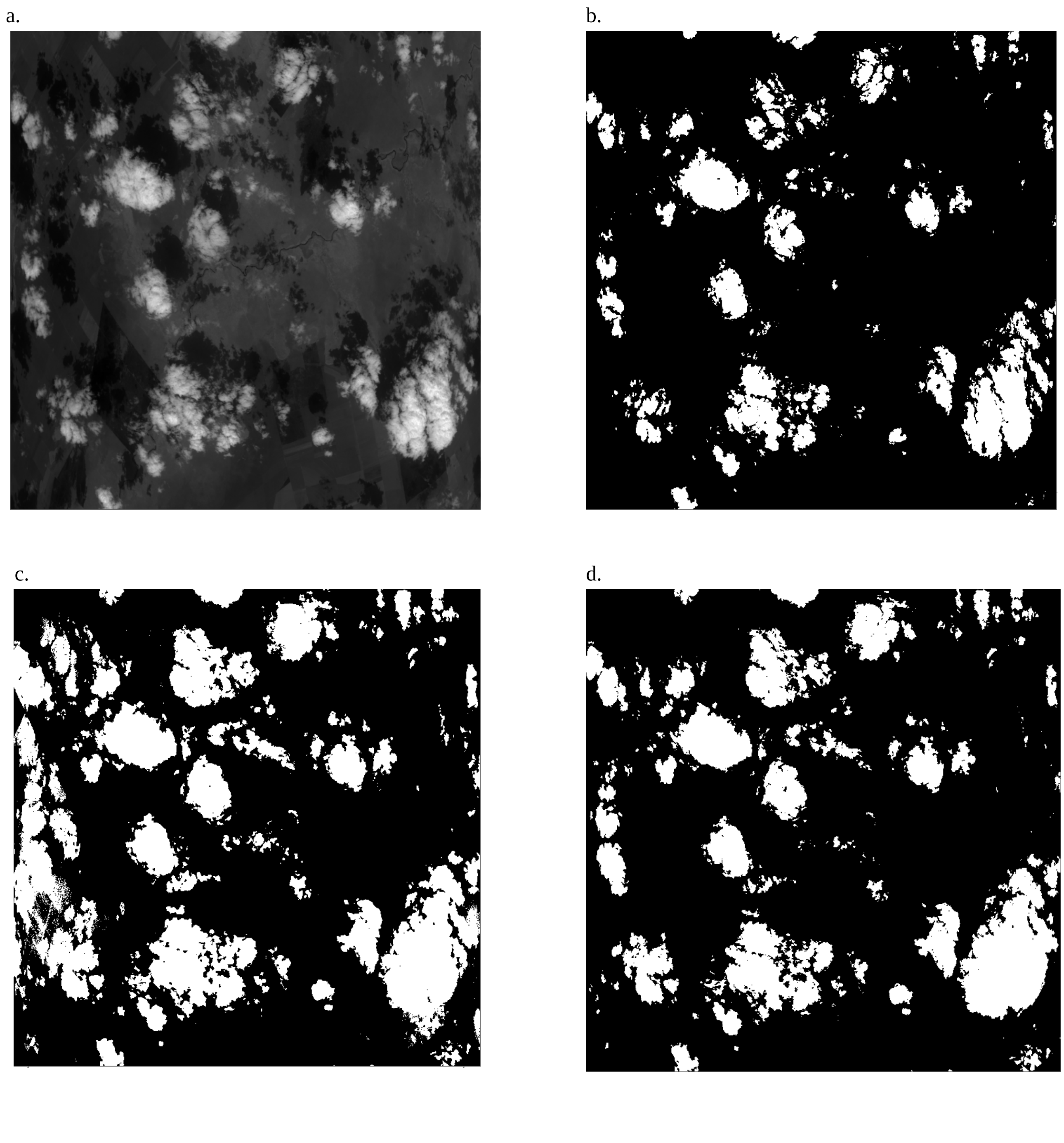

Figure 4. The original data is compared with the three cloud masking algorithm results. (a) Shows the actual scene, a portion of flight 95-163 shown in a near infrared band. (b) The MTI cloud masking algorithm results. (c) The MODIS cloud mask results. (d) The GENIE cloud mask results.

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